Review of Plutonium Attribute Measurement Technologies

Neutron Measurements:
Pu Mass & Absence of Oxide

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Attributes: Neutron Measurements

Attribute	Method	Specific Mechanisms
Pu Mass	**NMC & Pu600**	**—^{240}Pu-effective + isotopics**
Absence of Oxide	**NMC & Pu900**	**—Alpha > 0.5 and 870.8 keV line present**
Symmetry	**NMC & Symmetry Analyzer**	**—eight detector banks confirm symmetry**

Combine

High-Resolution
Gamma-Ray
Isotopic Measurement

Neutron Multiplicity
Measurement

$^{240}Pu\,/^{239}Pu$

with

^{240}Pu-effective mass

to obtain

Pu mass

Multiplicity Counting

- Three fundamental variables contribute to the neutron emissions from plutonium:

^{240}Pu-effective spontaneous fission rate	(α,n) neutron rate	induced fission rate

Primary Sources   Secondary Source

- In **Neutron Multiplicity Counting**, these three pieces of measured information are used with a mathematical model to deduce an assay value. Sample-dependent calibration is not required for many categories of materials.

Neutron Multiplicity Counting

Three elements are necessary:

(1) an efficient detector (typically 40–55%) with low die-away time and dead-time;

(2) electronics to obtain a distribution of multiplicities from the neutron pulse stream—the multiplicity shift register:

an MSR4, Canberra 2150, Aquila PSR-B, or Ortec/Antech AMSR; and

(3) a mathematical model to relate the measured quantities to the processes that produce the neutron pulse stream—the "point model."

The Point Model

Singles Rate:

$$S = F\varepsilon M \nu_{s1}(1+\alpha)$$

Doubles Rate:

$$D = F(f_D/2)\,(\varepsilon M)^2\,\{\nu_{s2} + [(M-1)/(\nu_{i1}-1)]\,\nu_{s1}(1+\alpha)\,\nu_{i2}\}$$

Triples Rate:

$$T = F\,(f_T/6)\,(\varepsilon M)^3\,\{\nu_{s3} + [(M-1)/(\nu_{i1}-1)][3\nu_{s2}\nu_{i2} + \nu_{s1}(1+\alpha)\,\nu_{i3}]$$

$$+\ 3[(M-1)/(\nu_{i1}-1)]^2\,\nu_{s1}(1+\alpha)\,\nu^2_{i2}\}$$

The Point Model

Detector Parameters:

ε = detection efficiency
f_D = fraction of doubles in the coincidence gate
f_T = fraction of triples in the coincidence gate

Source Parameters:

F = spontaneous fission rate = 473.5 fissions/s/g$*^{240}$Pu-effective mass
M = fission multiplication
α = ratio of (α,n) neutron rate to spontaneous fission rate

Nuclear Parameters:

(n = s $\Rightarrow$ spontaneous fission, n = i $\Rightarrow$ induced fission)

ν_{n1} = average number of neutrons produced per fission event

ν_{n2} = average number of neutron "pairs" per fission event

ν_{n3} = average number of neutron "triplets" per fission event

To Calibrate a Multiplicity Detector

Use a known ^{252}Cf source so that

$M = 1$ and $\alpha = 0$. Then,

$S = F\varepsilon\nu_{s1}$

$D = F(f_D/2)\,(\varepsilon)^2\,\nu_{s2}$

$T = F\,(f_T/6)\,(\varepsilon)^3\,\nu_{s3}$

where now

In principle, if a detector is properly optimized, representative standards are not needed for calibration in multiplicity counting.

F = spontaneous fission rate for the ^{252}Cf source
$\nu_{s1} = 3.75$
$\nu_{s2} = 11.96$
$\nu_{s3} = 31.81$

With F known for a given calibration source, can solve for ε, f_D, and f_T.

Drum Neutron Multiplicity Counter: A Fully Optimized System

- Detector head with junction box
- Computer
- Multiplicity shift register and power supplies

Measurements at Rocky Flats Environmental Technology Sites

Multiplicity Assay Results—Measurements of Weapons Components in ALR-8 Containers

Assay results corrected for container effects. ^{240}Pu-effective mass converted to Pu mass using reference isotopic ratios.

Average results are within 6% of reference values with a 30-minute count time.
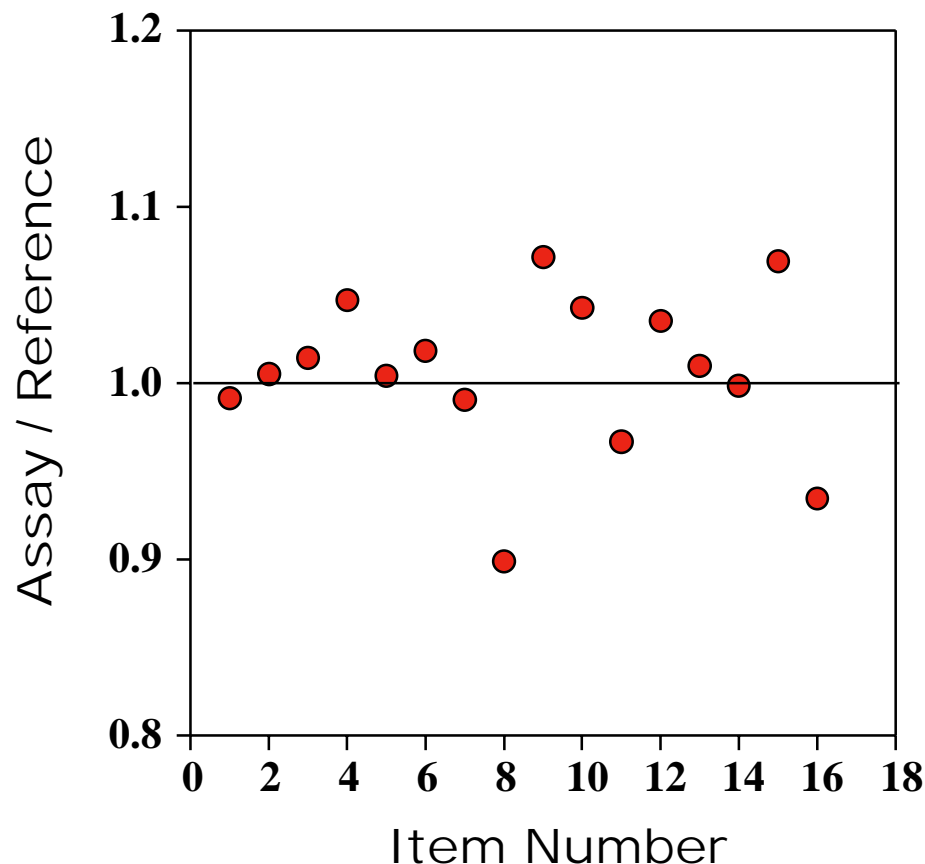
Neutron Multiplicity Counter

- Commercial coincidence counter designed for shipper/ receiver measurements.

- Adequate system for proof-of-principle.

- A fully optimized counter would require shorter count times and produce better multiplicity results.

Neutron Multiplicity Counter

84 cm

Doors

ALR-8

122 cm

Pallet
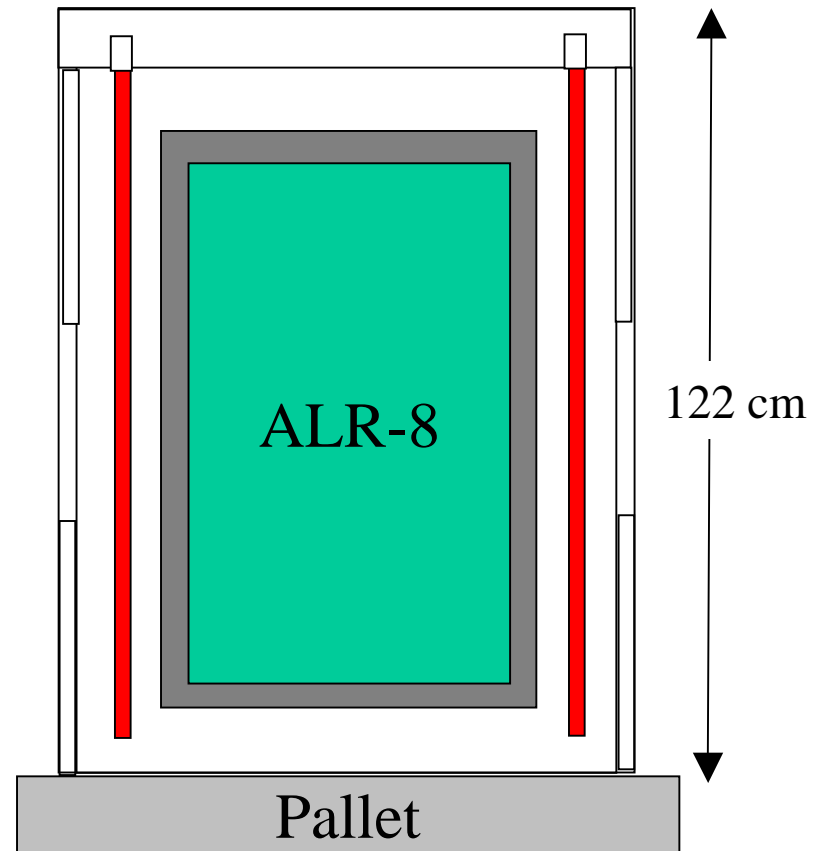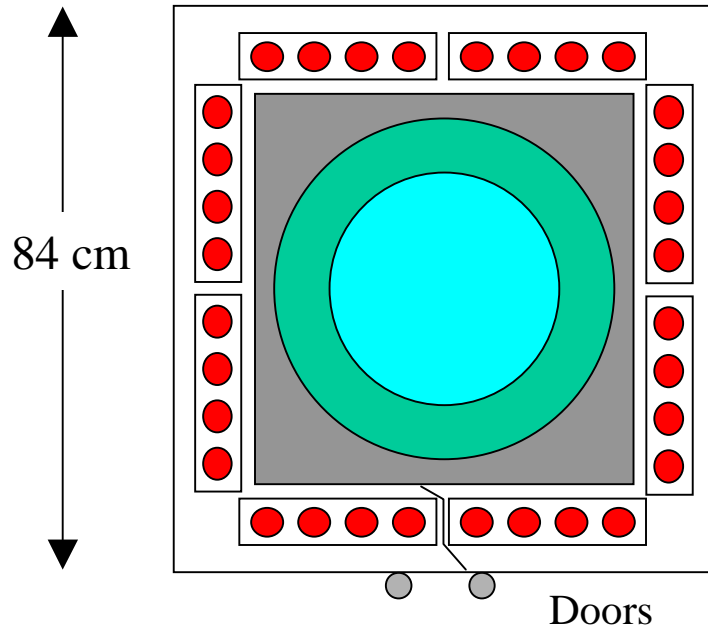
- 32 ^{3}He tubes, 102-cm active length
- Cavity and exterior are cadmium lined

Absence of Oxide

- Presence of oxygen causes the production of (alpha,n) neutrons.

- Pure metal samples yield zero (alpha,n) neutrons.

- A "non-zero alpha" is a potential indicator of oxide presence.

- However, a non-zero alpha can result from the presence of other low-Z elements such as fluorine, magnesium, aluminum, or beryllium.

- Alpha for pure, freshly separated, low-burn-up plutonium oxide is typically greater than 0.5.

Estimate of Alpha for Pure Pu Oxide

Alpha vs $^{240}Pu/^{239}Pu$ Content of PuO_2
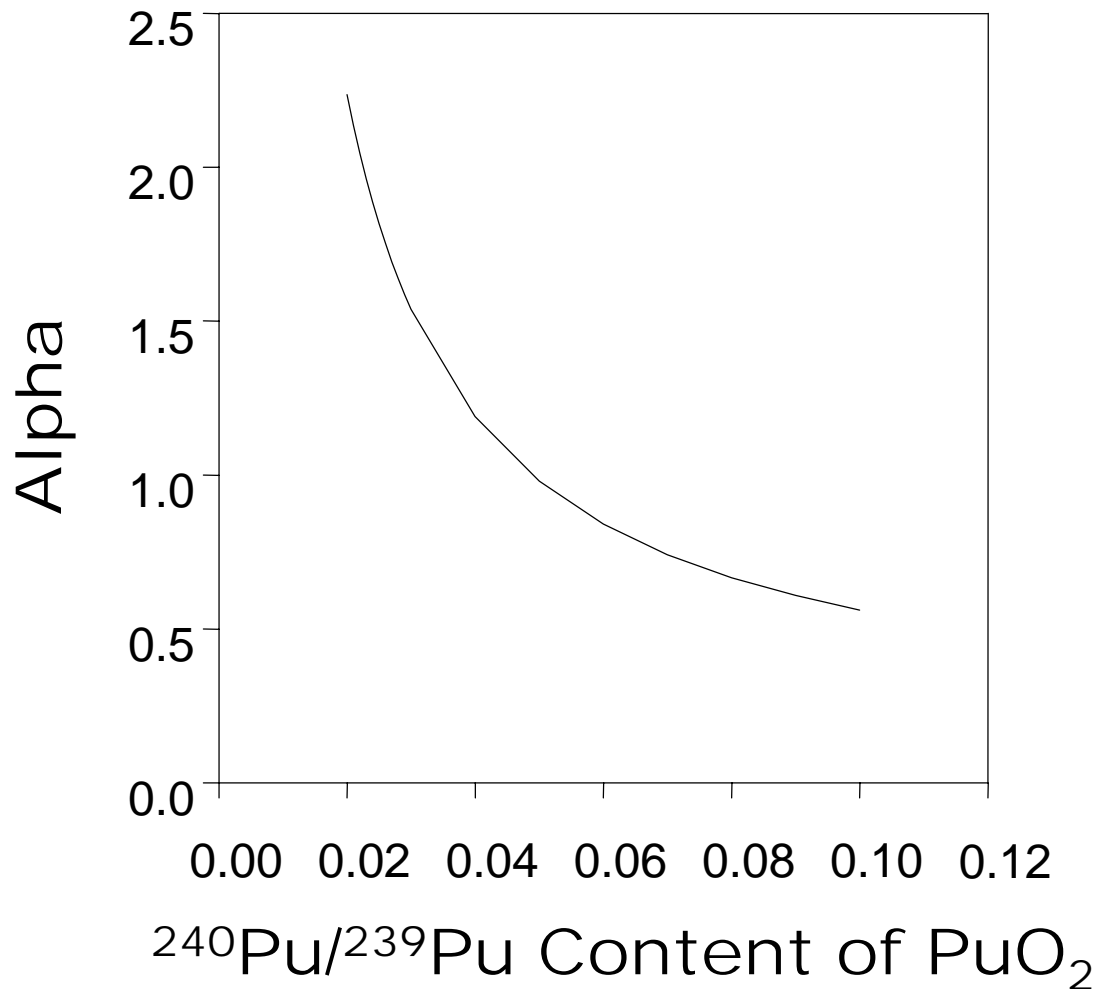
For pure, freshly separated plutonium oxide—assuming only ^{240}Pu and ^{239}Pu.

The existence of other isotopes will increase alpha in most cases.
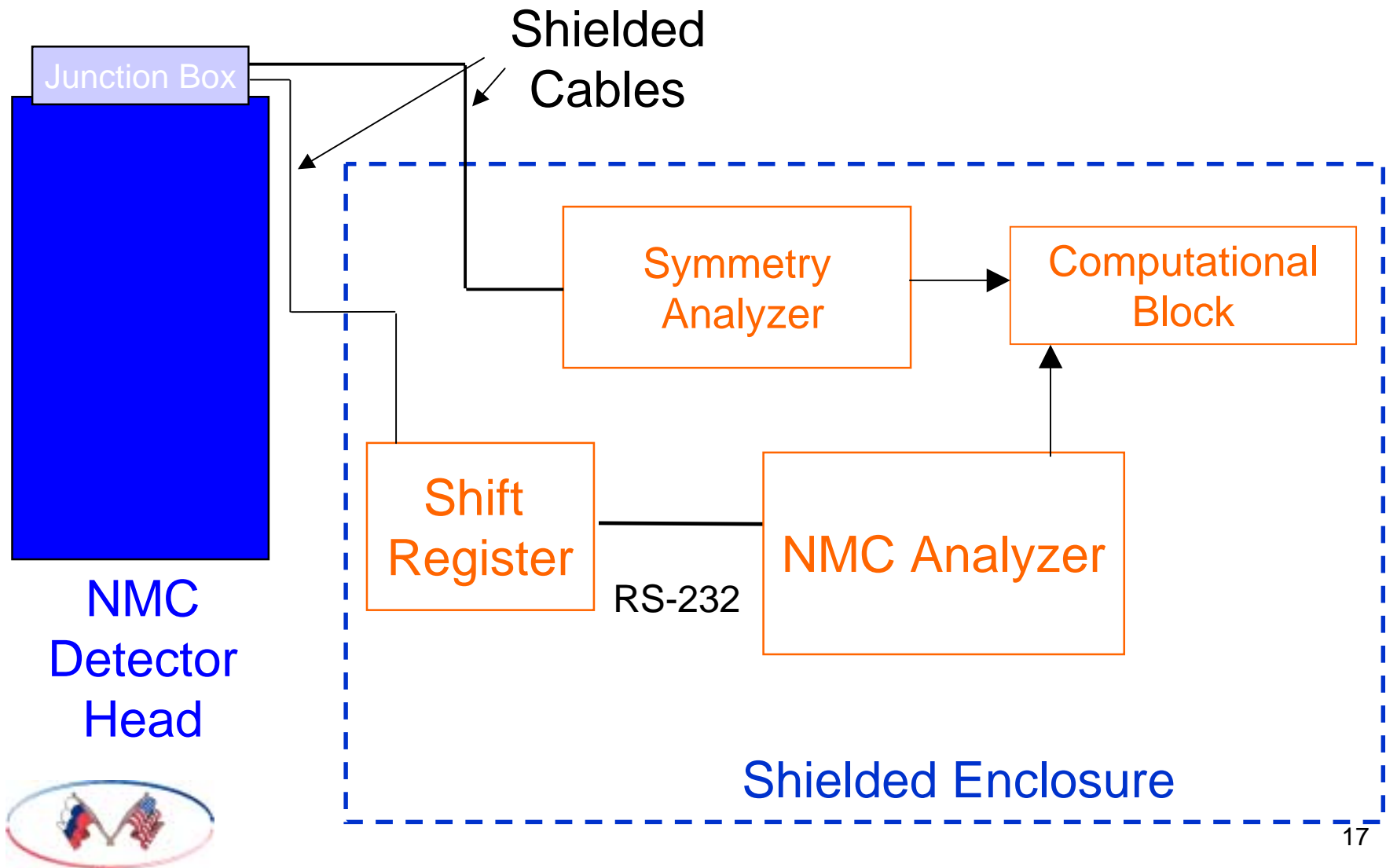
Features of Multiplicity Counting

- Accurate and robust

- Proven technology already in use for international inspections

- Can be authenticated with nonsensitive materials

- Can distinguish plutonium from isotopic neutron sources such as ^{252}Cf or AmLi

- Requires isotopic ratio information to determine total mass of Pu
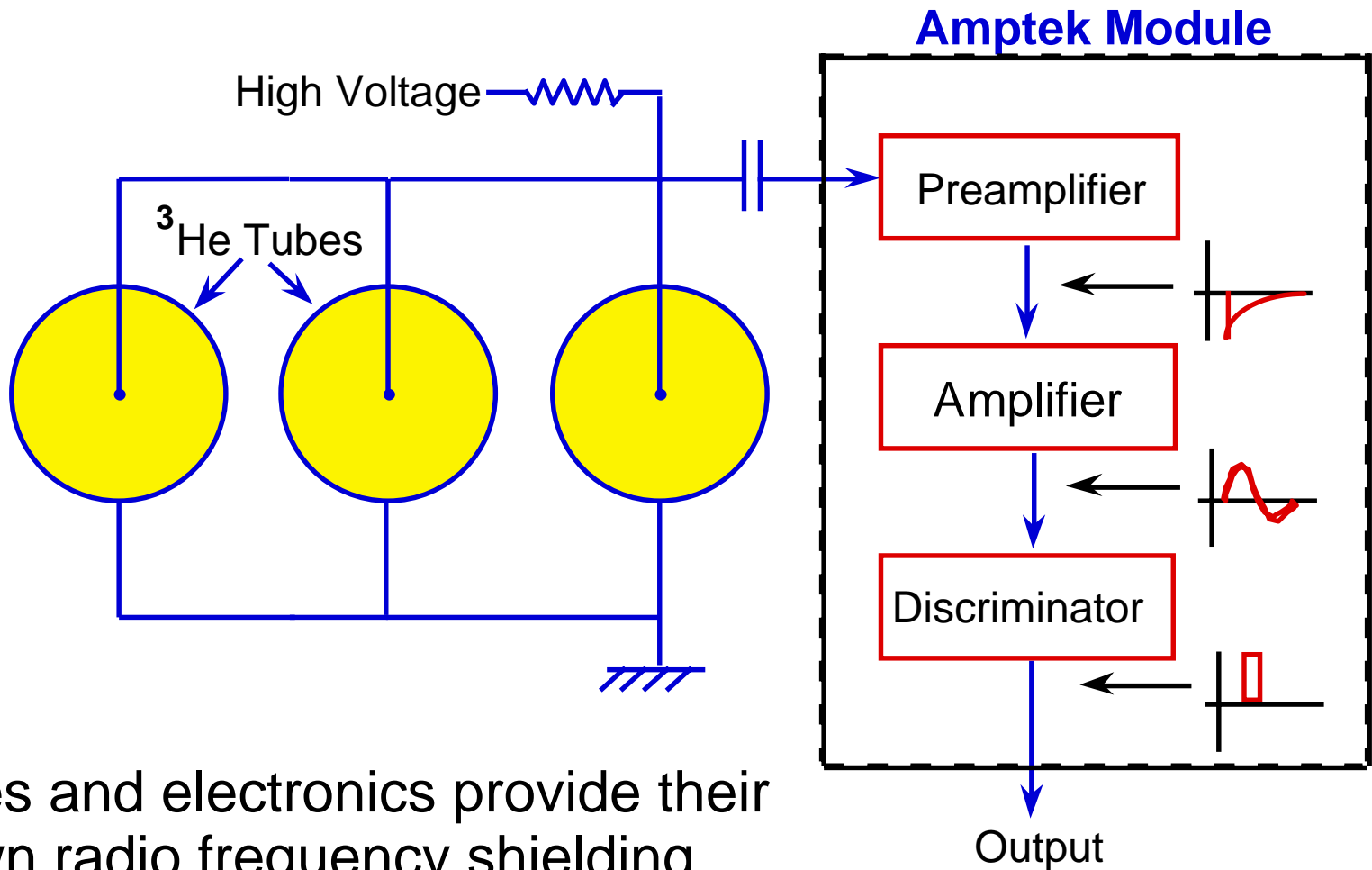
NMC System

Shielded Cables

Junction Box

Symmetry Analyzer

Computational Block

Shift Register

NMC Analyzer

RS-232

NMC Detector Head

Shielded Enclosure

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Portable Shift Register (PSR-B)

IB Considerations for the Detector Head Electronics

Amptek Module

High Voltage

^{3}He Tubes

Preamplifier

Amplifier

Discriminator

Output

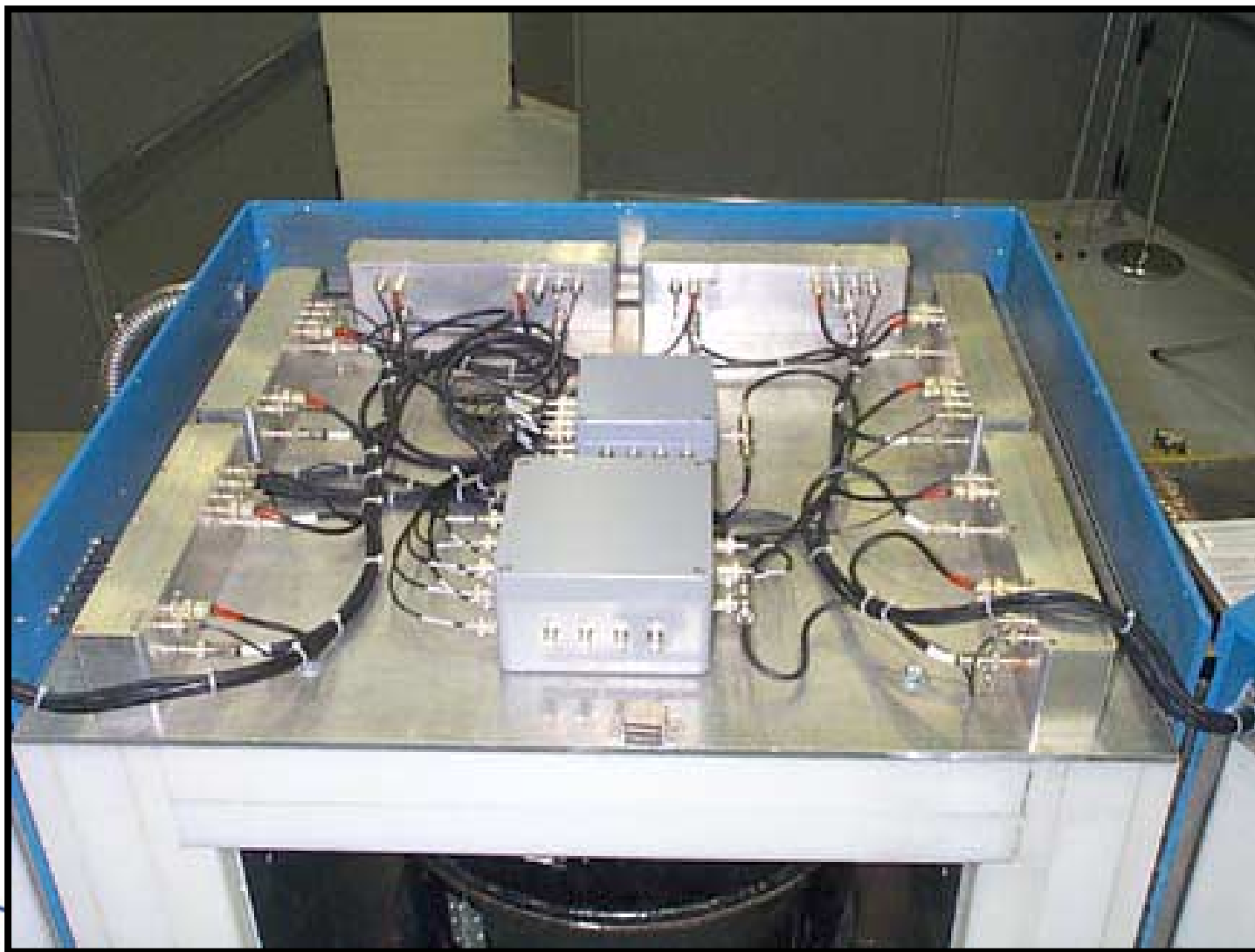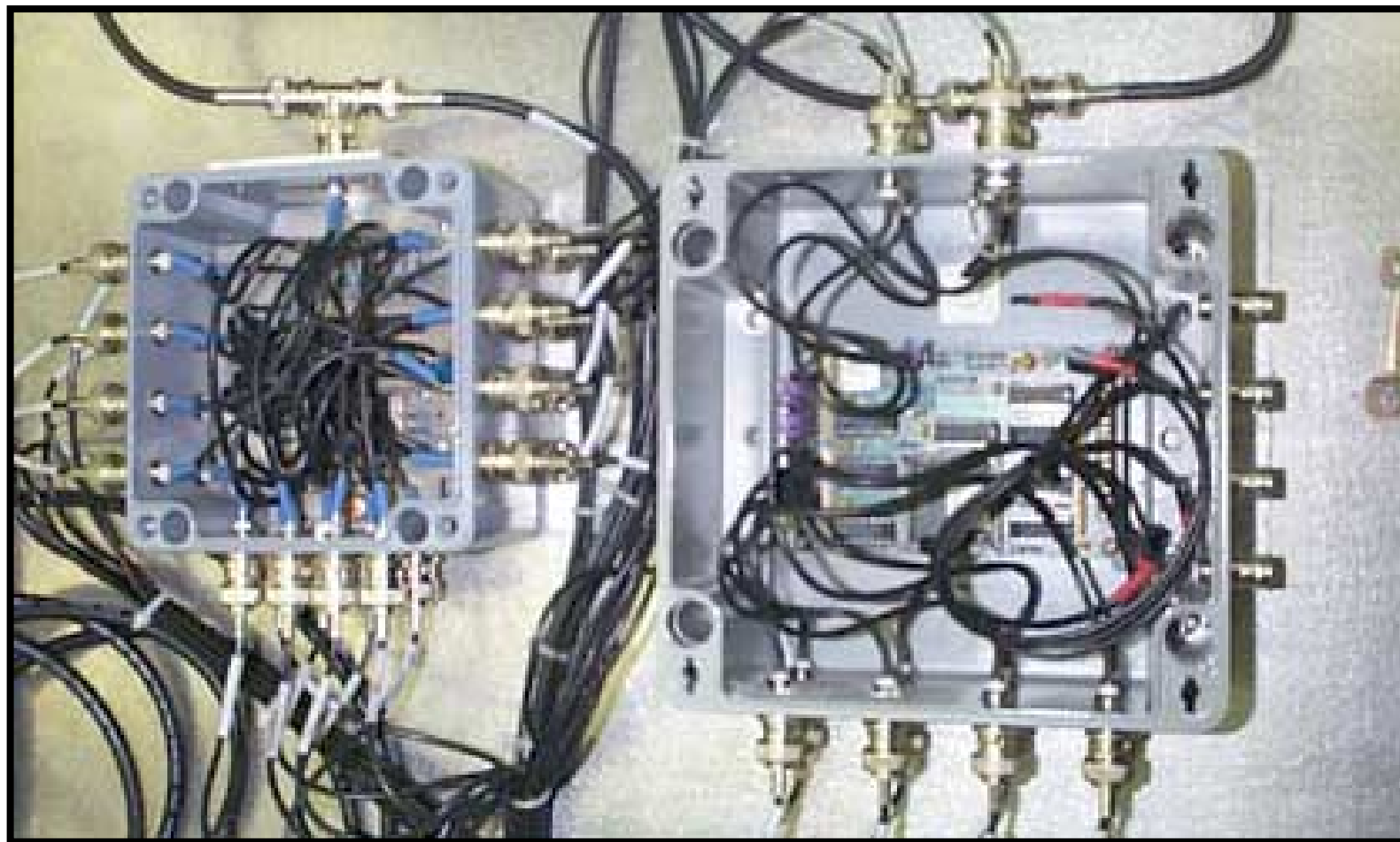Tubes and electronics provide their own radio frequency shielding.

Detector Head Electronics
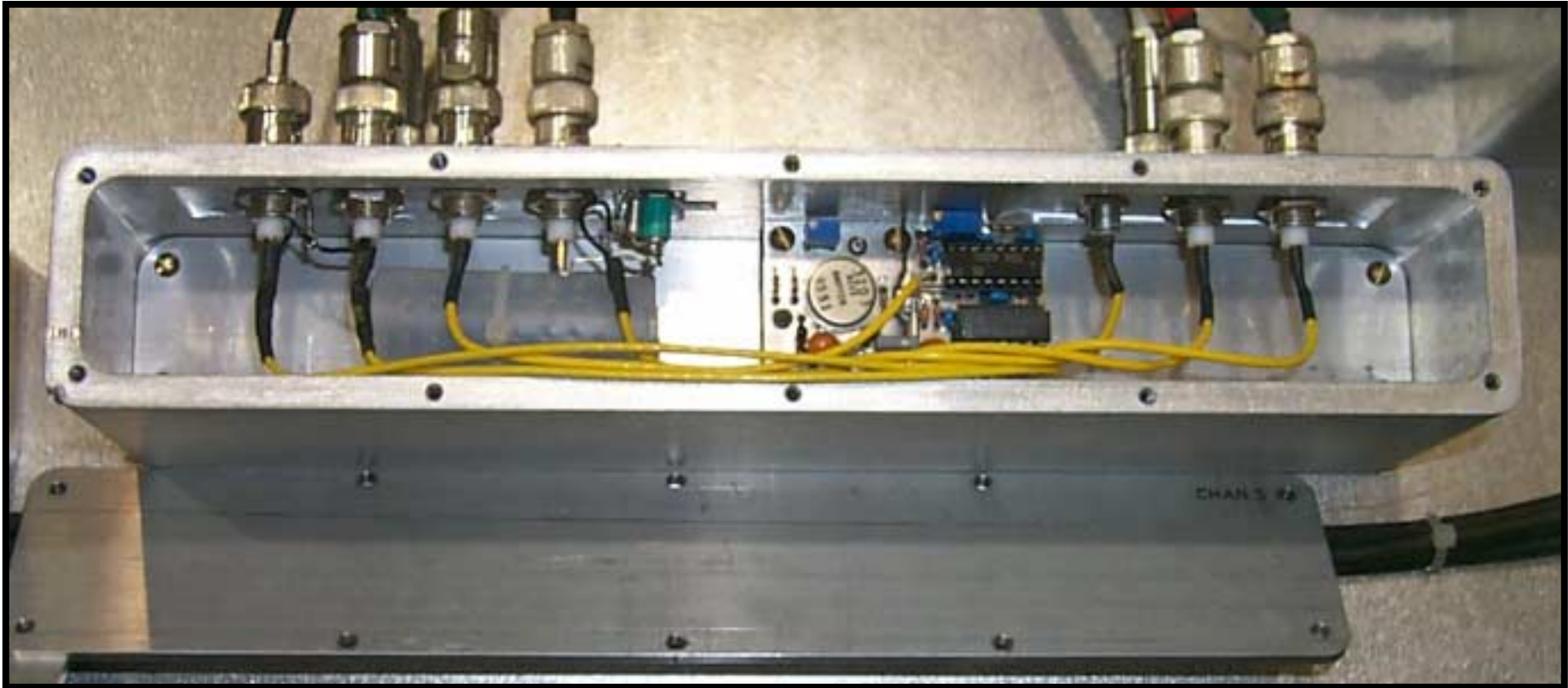
Detector Electronics

Detector Electronics

NMC Electronics